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THE EFFECT OF NOSE SHAPE ON THE PENETRATION OF SMALL-SCALE MK 82 BOMBS IN SOIL

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NAVAL ORDNANCE LABORATORY, WHITE OAK, SILVER SPRING, MARYLAND

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Additional tests were conducted to determine the effect of the medium on the trajectory of the projectile. From tests into clay, sand, and stratified layers of clay and sand, it was found that the effectiveness of modeling depends on the knowledge of the properties of the penetrated medium.

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THE EFFECT OF NOSE SHAPE ON THE PENETRATION OF SMALL-SCALE MK 82 BOMBS IN SOIL

This study was conducted to determine the effect of nose shape on the penetration characteristics of the Mk 82 bomb in various types of soils.

The authors would like to express their appreciation to the many individuals who assisted in this undertaking, especially Messrs. B. Wolfe, W. Watt, W. Farley and J. Abell for their assistance in conducting the experiments.

GEORGE G. BALL
Captain, USN
Commander

a. E. Seigel
A. E. Seigel
By direction

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INTRODUCTION

The effectiveness of a weapon system using the Mk 82 bomb requires that the bomb follow a specific trajectory during earth penetration to a terminal location of desired depth. Since the destructive capability of the bomb is severely impaired if the bomb penetrates too deeply, it is desirable for the bomb to have a trajectory similar to type A shown in Figure 1. Also, it is desirable for the bomb to achieve such a trajectory for a range of impact velocities and impact angles so that overly tight restrictions are not placed on the flight conditions prior to impact. However, field tests indicate that the trajectory of the bomb is somewhat erratic, and it will frequently follow a trajectory similar to type B or a trajectory outside the vertical flight plane. Therefore, it was decided to investigate the effect of nose shape, impact velocity, and impact angle on the trajectory of the bomb in an effort to consistently achieve the desired trajectory. Modifications to the nose shape were permitted forward of the section where the nose fuze plug is attached to the Mk 82 body. A series of tests were conducted on 1/25-scale models of the bomb with three basic nose configurations. These nose configurations are the ogival, conical, and spherical nose shapes which are shown in Figure 2a. The ogival configuration is the existing profile nose used on the full-scale bomb. This configuration was chosen to confirm the results of full-scale tests, and thus determine the feasibility of model testing for this particular application. The conical and spherical configurations were chosen to examine the relative trajectory characteristics of a more pointed and more blunted nose profile, respectively.

The flat nose shape shown in Figure 2b was tested in mediums such as dry-packed sand, dry-hardened sculptor's clay, and stratified layers of clay and sand. These mediums were chosen to simulate conditions for which additional full-scale data are available. The Mk 32 Mod 1 bomb used in the tests has a collar for the arming device similar to that of the flat nose shape used in these model tests.

TEST FACILITY AND MODELS

A picture of the 1/25-scaled configurations of the Mk 82, 500-pound, low-drag bomb is given in Figure 3. Table 1 lists the physical properties of both the prototype and the scale models. Polycarbonate sabots encapsulated the models which were launched horizontally from a 20mm powder gun as shown in Figure 4. The target was a 2' x 3' x 4' box filled with a tamped silty sand-type of soil. The box was placed on a pivot mount which could be rotated to desired impact angles ranging from 15 degrees to 75 degrees. Model velocities in these tests ranged from 250 feet per second to 1500 feet per second, and were measured by three photoelectric stations used to activate three time-interval counters. The flight attitude of the model was recorded immediately prior to impact by horizontal and vertical X-ray units. These units were triggered by a time-delayed signal from a fourth photoelectric station.

The trajectory characteristics of the model in soil were determined by a relatively simple technique. The wake of the trajectory remained as a cavity filled with disturbed soil. Therefore, it was possible to insert a flexible plastic rod into this cavity which would follow the trajectory to the terminal location of the model. A trench was then made along the rod as shown in Figure 5, and the trajectory characteristics were measured with reasonable ease and accuracy.

A different technique was used for measuring the trajectory in sand and clay. The sand was packed in layers 2 inches thick, separated by cellulose acetate sheets; and the trajectory was traced by the holes left in these sheets. Similarly, the clay was placed in layers 2 inches thick, which were left intact except for the penetration cavity. This cavity in the clay was also used for determining the trajectory in the stratified layers of clay and sand (top layer was clay).

TEST RESULTS

The trajectory data of the conical and ogival configurations tested at a 30-degree impact angle are given in Figure 6. The erratic trajectories of the ogival configuration verify the full-scale findings. Only one test shot was made for the conical configuration since it was expected to produce similar or less favorable results than the ogival. However, the penetration information was used in the dimensional analysis to follow.

The spherical nose configuration was launched at impact angles of 30 degrees and 45 degrees. The results, given in Figure 7, show that the trajectories are for the most part favorable and consistent. There are two cases which follow the unfavorable nose-down trajectory, but these experienced some unusual circumstances. It is felt that any configuration will have the tendency to nose down if it had a pitch-down attitude prior to impact. As a result of these tests it is maintained that the spherical nose is less sensitive to these flight line deviations, and thus a larger deviation is required to have a significant effect on its trajectory. The vertical X-ray of shot number 1309 shows that the model had a pitch-down attitude which was noticeably larger than the other spherical nose tests. Shot number 1314 was launched at an impact angle of 45 degrees and velocity of 1585 feet per second which was 600 feet per second faster than any other shot. The attitude of the model cannot be accurately determined due to the inaccuracy of the X-ray alignment, but it is possible that the combination of steeper impact angle and higher velocity may have sufficiently amplified the effect of any attitude deviation. It is worth mentioning that this latter problem is of little concern since the velocity is inordinate to full-scale application.

The trajectory data of the flat nose configuration tested at an impact angle of 48 degrees in sand and clay are given in Figures 8a, 8b, and 8c. The trajectories in sand, clay, and stratified clay and sand were all favorable. However, there was evidence of instability in the sand firings since there were large deviations from the vertical flight plane. The penetration path lengths in sand and clay are inconsistent with full-scale results which indicate greater travel in clay than in sand. The model tests show path lengths which are about the same in sand and clay (accounting for velocity variations), or which are possibly even longer in sand. Differences in the properties of the actual and simulated soils would be a reasonable explanation for this discrepancy, but this possibility cannot be verified since the properties were not determined for the full-scale tests.

THEORETICAL ANALYSIS

A theoretical soil penetration expression for normal impact developed by John Harri, reference (1), on an energy basis is examined for utilization in predicting the response of the prototype.

Total energy available = $P \cdot E + K \cdot E = WS + \frac{1}{2}MV^2$

Total energy loss = K E due to lateral soil movement + friction

+ work done in compressing the soil laterally and soil crushing and grinding =

$$\int_0^S [\tfrac{1}{2} \frac{\rho \pi r^2}{g} (\frac{df}{dx})^2 (\frac{dx}{dt})^2 + b\mu A_B P_L X + \int_0^r KC 2\pi r \, dr] dx$$

Penetration expression

$$S = -[KC + \tfrac{1}{4} \frac{\rho}{g} (\frac{df}{dx})^2 V^2 - \frac{W}{A_n}] + [KC + \tfrac{1}{4} \frac{\rho}{g} (\frac{df}{dx})^2 V^2 - \frac{W}{A_n}]^2 + \frac{MV^2}{A_n}$$

$$b\mu \frac{A_B}{A_n} P_L \quad b\mu \frac{A_B}{A_n} P_L \qquad (1)$$

A parametric study using this equation and model test results give the soil characteristics as shown in Figure 9. The graph indicates that the friction energy term is not very significant for the model tests, where in the actual test it is very significant, see Figure 10. With the soil constants estimated from the parametric study, the penetration expression is applied to the actual testing of the 500-pound SNAKEYE unretarded bomb Mk 82. The result is compared with the field test results of the actual bomb, see Table 1.

Table 1. 500-pound SNAKEYE Unretarded Bomb - Mk 82

		penetration depth (ft)
Experimental	sandy clay	15.5
	sand	10.6
Scaling	from models	8.6
Theoretical	from Harri	18.6

SCALING EQUATIONS

Existing empirical studies were examined for utilization in the prediction of the response of the prototype. Since the problem of earth penetration by a projectile was studied as early as 1742, the most notable approaches were that of Poncelet (1829) and Petry (1910). Their empirical equations, together with the more recent work of Laumbach (1964) and Young (1967), are listed in Table 2.

Table 2. Existing Empirical Formulas
(Refs. (2), (3), (4) and (5))

Poncelet: (1829) $$P = \frac{W}{2Ajb_o} \ln \left(\frac{1+b_oV^2}{a_o}\right)$$

Petry : (1910) $$P = \frac{W}{A} K \log_{10} \left(1 + \frac{V^2}{215{,}000}\right)$$

Laumbach: (1964) $$P = K \frac{W}{A} \ln (a + bV^2)$$

Young : $$P = 0.53\ SN \left(\frac{W}{A}\right)^{\frac{1}{2}} \ln (1+2V^2 10^{-5}) \quad (V < 200)$$

(1967) $$P = 0.0031\ SN \left(\frac{W}{A}\right)^{\frac{1}{2}} (V-100) \quad (V > 200)$$

Letting the soil constants and the velocity of impact be the same for the model and the prototype testing, we can utilize these empirical formulas as scaling equations to obtain the response of the prototype from the results of the model testing.

Table 3. The Characteristics of the Model and the Mk 82 Bomb

Prototype:	
diameter of projectile	14 inches
impact velocity	
weight of projectile	454,000 grams
Model:	
diameter of projectile	0.43 inch
impact velocity	906 ft/sec
weight of projectile	19 grams
depth of penetration	21.5 inches

These results are then compared with the field test results of the Mk 82 bomb.

Table 4. 500-pound SNAKEYE Bomb - Mk 82

	Velocity (ft/sec)	Soil Type	Penetration depth (ft)
Poncelet Petry Laumbach	666		24.8
	906		34
Young	666		6
	906		8.1
Experimental Field Test	670	sandy clay	10-25
	710	sand	9-20
	800	sandy clay	15-26
	850	sand	11-15

DIMENSIONAL ANALYSIS

The tests were analyzed with the view of obtaining information regarding the relationship between the penetration of the projectile, the impact velocity, the weight of the projectile, the diameter of the projectile and the nose shape of the projectile. Results of the penetration tests suggest a functional relationship governing the penetration phenomena of the form:

$$f(S,V,m,\sigma,D,\rho,g,\mu,\alpha) = 0 \qquad (2)$$

where S = maximum depth of penetration

V = impact velocity

ρ = mass density of soil

D = diameter of projectile

μ = friction factor

m = mass of projectile

g = gravitational acceleration

α = angle of entry

σ = compressible strength of soil

From this relationship, many dimensionless ratios can be obtained. The fundamental dimensionless ratios (see Appendix A for the determination of the π's) are:

$$\pi_1 = \frac{S}{D}$$

$$\pi_2 = \frac{V^2}{dg} \text{ --> Froude number}$$

$$\pi_3 = \frac{m}{D^3\rho} \text{ --> Euler number}$$

$$\pi_4 = \frac{\sigma}{D\rho g}$$

$$\pi_5 = \mu$$

$$\pi_6 = \alpha$$

Figures 6 and 7 show the results of the penetration of projectiles with different nose geometries into simulated earth targets for several impact velocities. In this diagram, the maximum depth of penetration divided by the projectile diameter and multiplied by the square root of the Euler number is plotted against the square root of the Froude number.

$$\frac{Sm^{\frac{1}{2}}}{D^{5/2}\rho^{\frac{1}{2}}} \text{ vs } \frac{V_o}{(Dg)^{\frac{1}{2}}} \tag{3}$$

These data indicate that the relation of the parameters is a straight line and can be expressed by the equation

$$\left[\frac{Sm^{\frac{1}{2}}}{D^{5/2}\rho^{\frac{1}{2}}}\right] = K \left[\frac{V_o}{(gD)^{\frac{1}{2}}}\right]$$

where

k = slope of the curve shown in Figures 6 and 7.

Of interest is the prediction of the maximum depth of penetration of the full-size prototype from the results of model testing. The soil is taken to be the same during the actual case and the model testing and both $g\rho$ can be considered as constants. With the straight line relationship the following relation can be established:

$$\frac{S_p W_p^{\frac{1}{2}}}{D_p^2 V_p} = \frac{S_M W_M^{\frac{1}{2}}}{D_M^2 V_M}$$

Many other scaling equations can be obtained by combining the fundamental dimensionless ratios. For instance, we can obtain Poncelet, Petry and Laumbach's empirical equations by plotting π_1 against $(\pi_3\pi_2)/\pi_4$; and Young's equation by plotting π_1 against $(\pi_2\pi_3)^{\frac{1}{2}}$.

It is interesting to note that the curve, obtained by fitting the theoretical expression to our model test data, is of the same form as the empirical equations of Poncelet, Petry, Laumbach and Young.

With these wide choices of scaling equations and wide range of results, a considerable amount of testing and analysis is necessary with different scaled models to develop an accurate and meaningful scaling equation.

CONCLUSIONS AND RECOMMENDATIONS

The similarity of the test results for the scale model and prototype of the Mk 82 supports the contention that the results for other scaled configurations are representative of the response of their full-scale counterparts. The spherical nose configuration appears to have the stability to achieve a relatively consistent and reproducible trajectory of the desired shape. Since such trajectories were achieved for a broad range of impact velocities and impact angles of 30 degrees and 45 degrees, the required flight conditions prior to impact are not highly restrictive. It is recommended that further tests be conducted in different soils for a greater variety of impact angles and for shapes blunter than the spherical configuration. Also, additional tests for models two or three times larger would significantly improve the scaling laws developed in this study. Scaling equations obtained from dimensional analysis and the empirical penetration equations investigated yielded a wide range of predicted penetration depth. However, even considering the worst case obtained from the scaling laws investigated of 34 feet, the trajectory of a blunted nose at 30-degree entry is such that the total vertical depth of penetration is not likely to exceed 10 feet. This is within the desired range for an effective bomb. A considerable amount of testing and analysis of the test data, as well as a theoretical study, is necessary before general valid conclusions can be drawn on the penetration of projectiles into earth targets.

The effectiveness of modeling for predicting the penetration behavior of projectiles depends on the knowledge of the properties of the penetrated medium. From these tests in silty sand, sand, and clay, it is maintained that model testing is a feasible technique for determining the response of a penetrating projectile if typical soil properties can be reproduced in the laboratory.

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(3) Petry, M., "Monographies de Syste'mes d'Artillerie," Brussels, 1910

(4) Laumbach, D. D., "A Soil Penetration Analysis Applied to Experimental Data," Sandia Corp., SCTM-64-57, Mar 1964

(5) Young, C. W., "The Development of Empirical Equations for Predicting Depth of an Earth Penetrating Projectile," Sandia Corp., SC-DR-67-60, May 1967

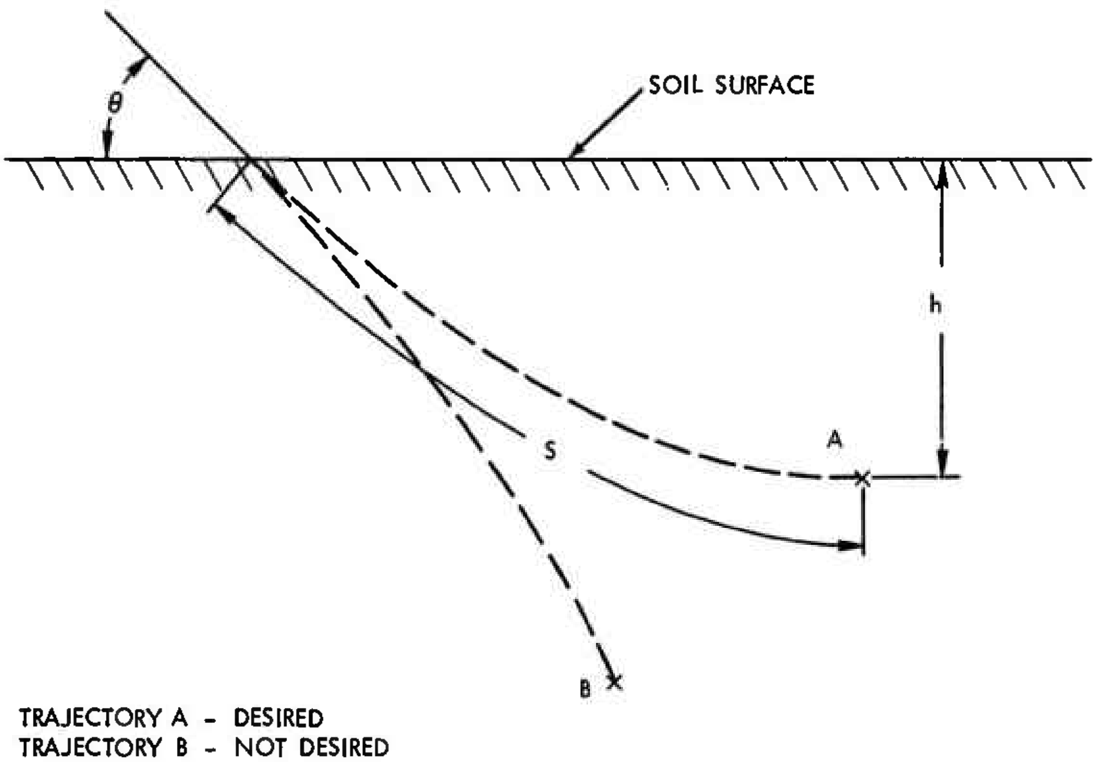

FIG. 1 TYPICAL TRAJECTORY SHAPES

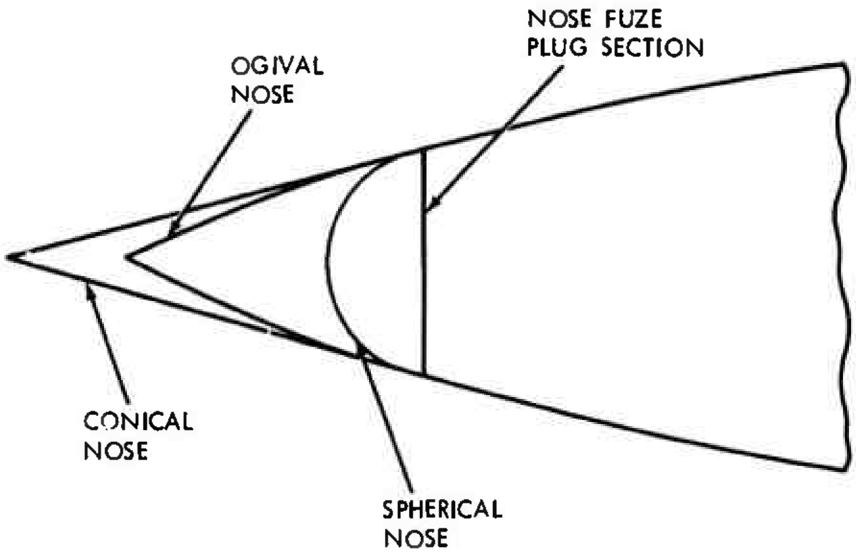

FIG. 2a OGIVAL, CONICAL, AND SPHERICAL NOSE CONFIGURATIONS

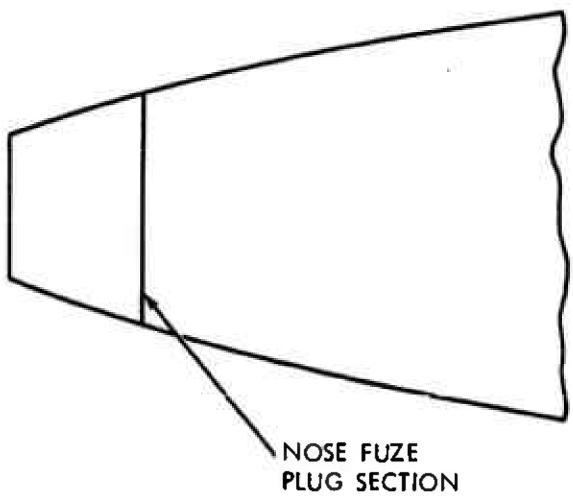

FIG. 2b FLAT NOSE SECTION

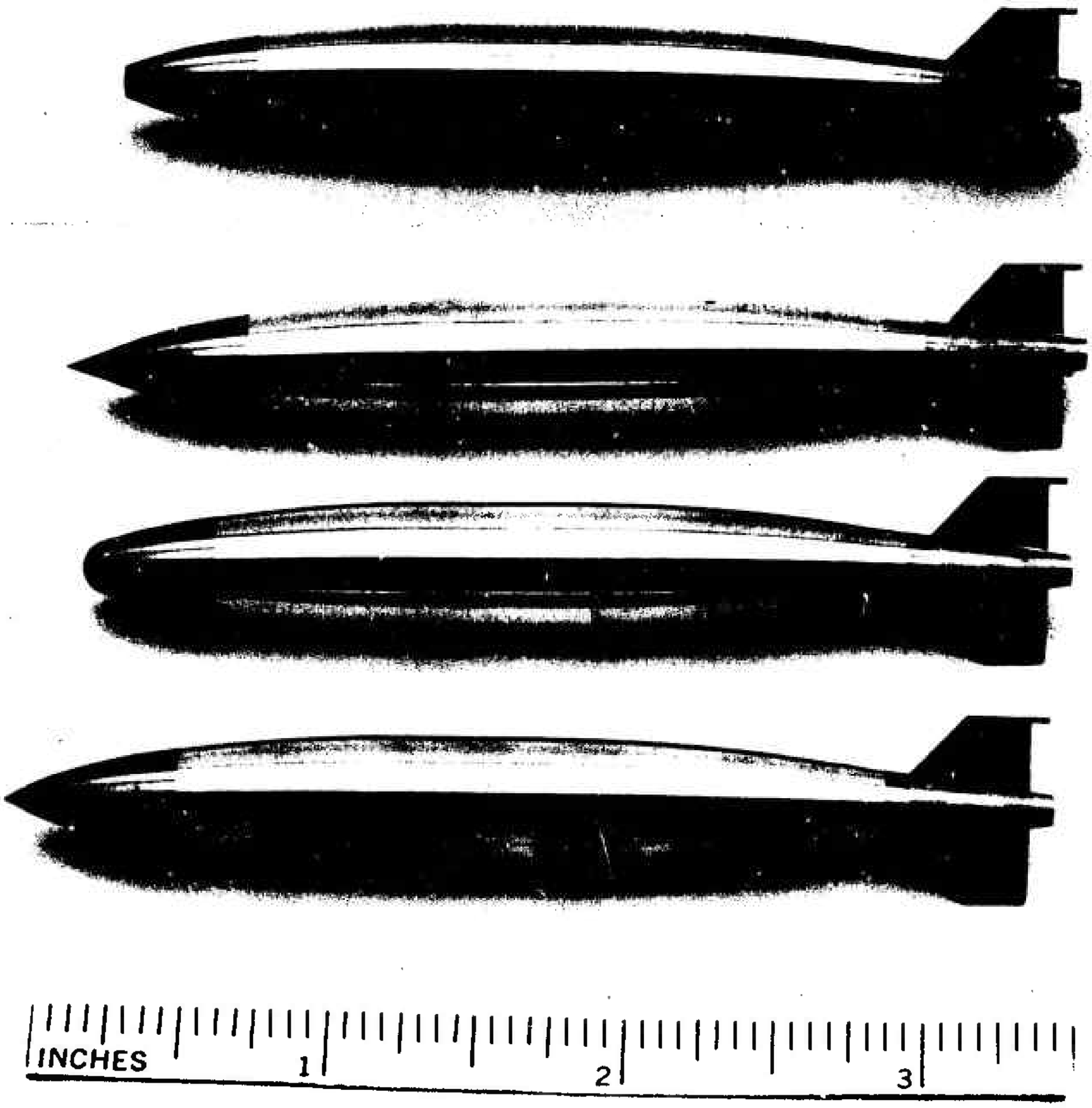

FIG. 3 1/25 SCALE MODELS

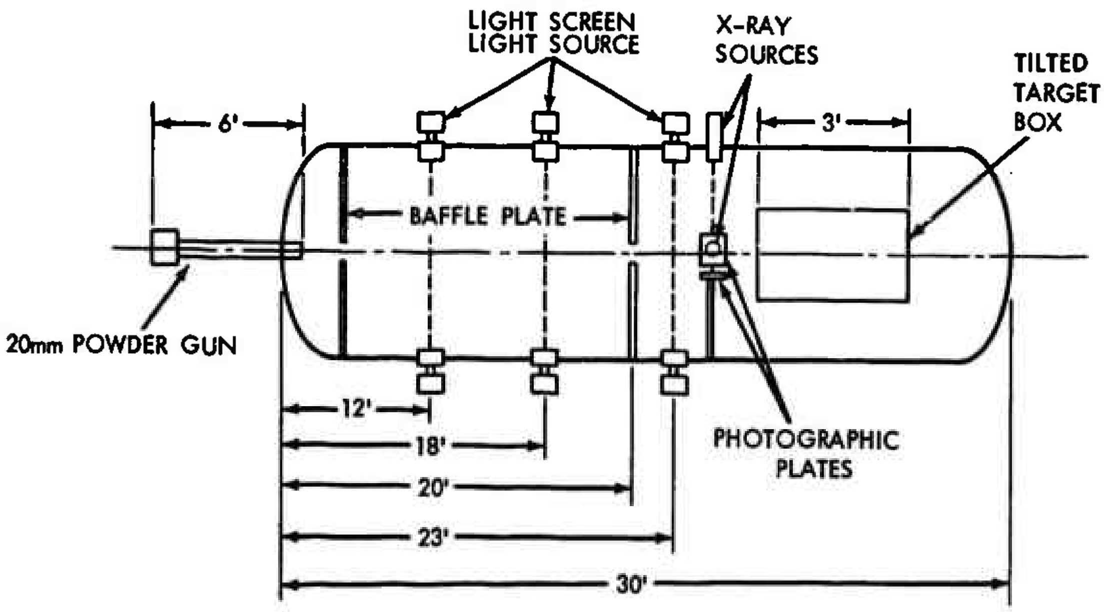

FIG. 4 SCHEMATIC OF TEST FACILITY

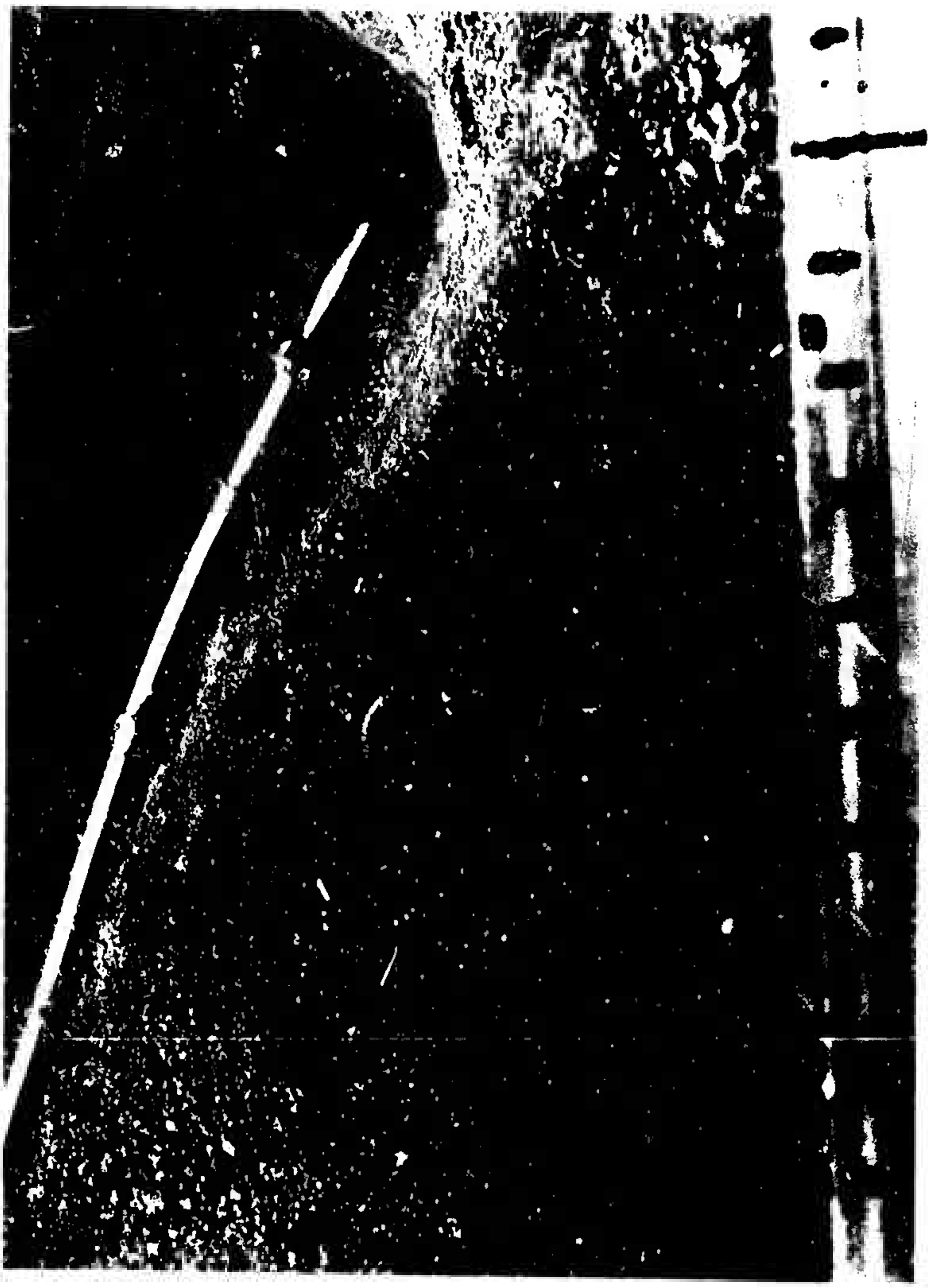

FIG. 5 TRAJECTORY OF PROJECTILE IN SILTY-SAND SOIL

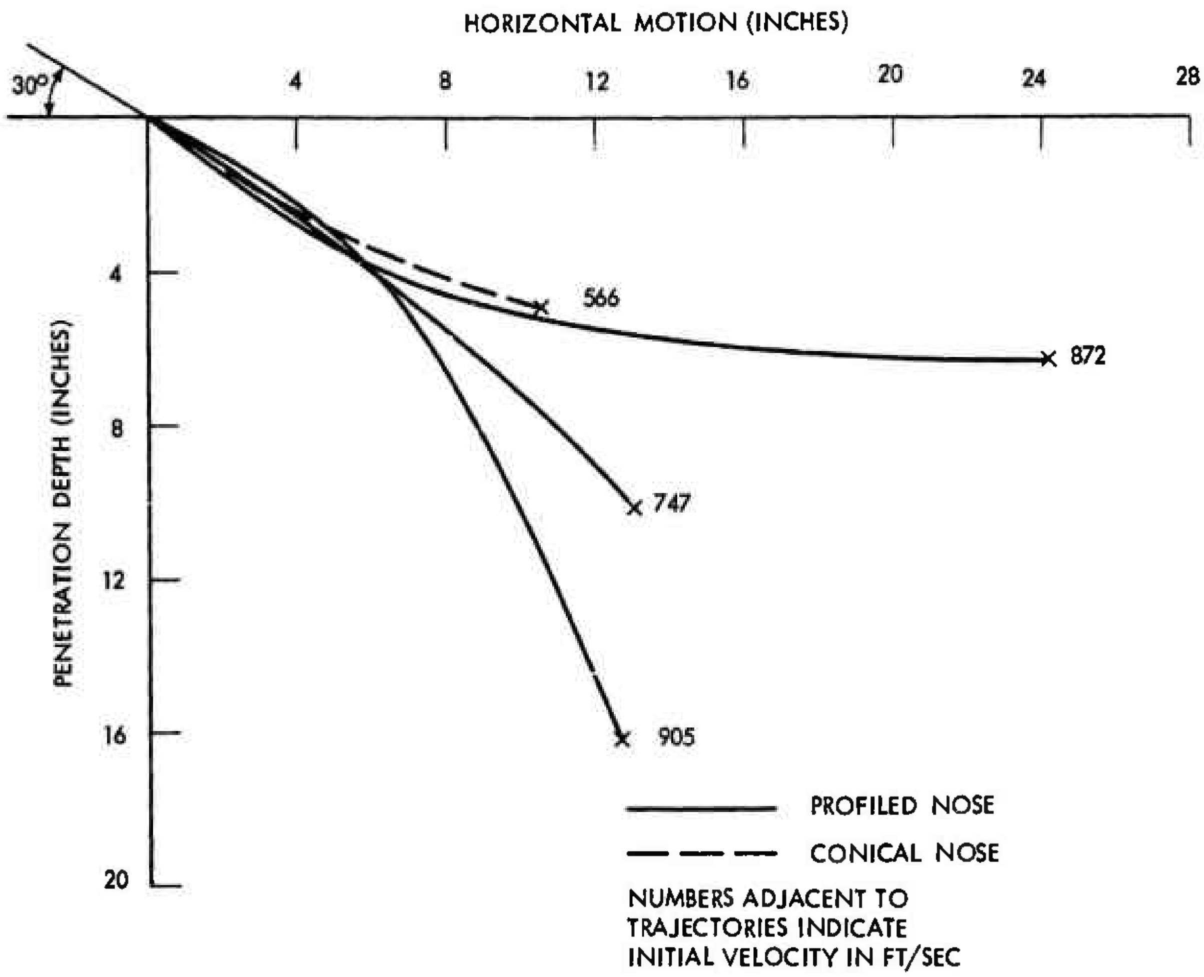

FIG. 6 TRAJECTORY DATA OF CONICAL AND OGIVAL NOSE CONFIGURATIONS AT 30° IMPACT ANGLE IN SILTY-SAND

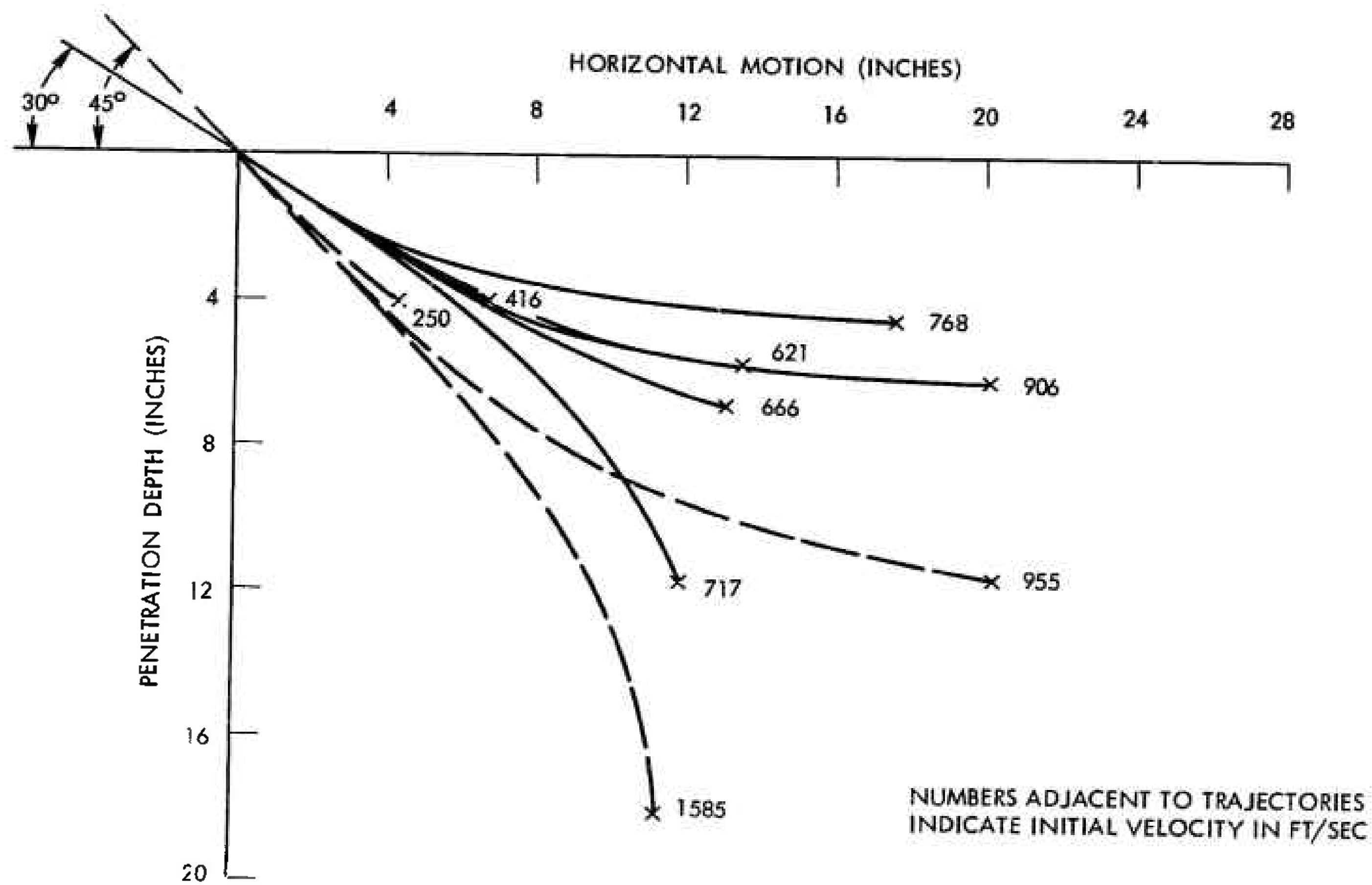

FIG. 7 TRAJECTORY DATA OF SPHERICAL NOSE CONFIGURATION AT 30° AND 45° IMPACT ANGLES IN SILTY-SAND

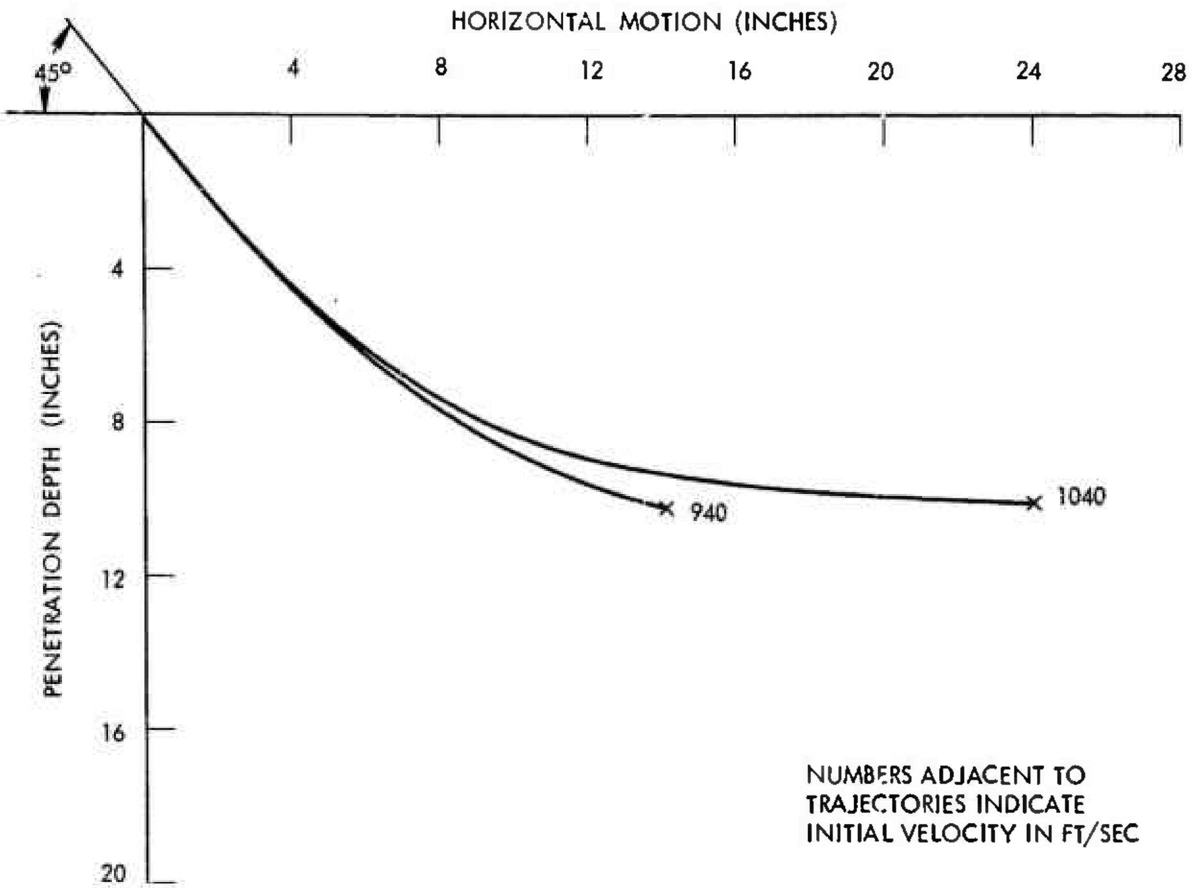

FIG. 8a TRAJECTORY DATA OF FLAT NOSE CONFIGURATION
AT 48° IMPACT ANGLE IN HARD CLAY

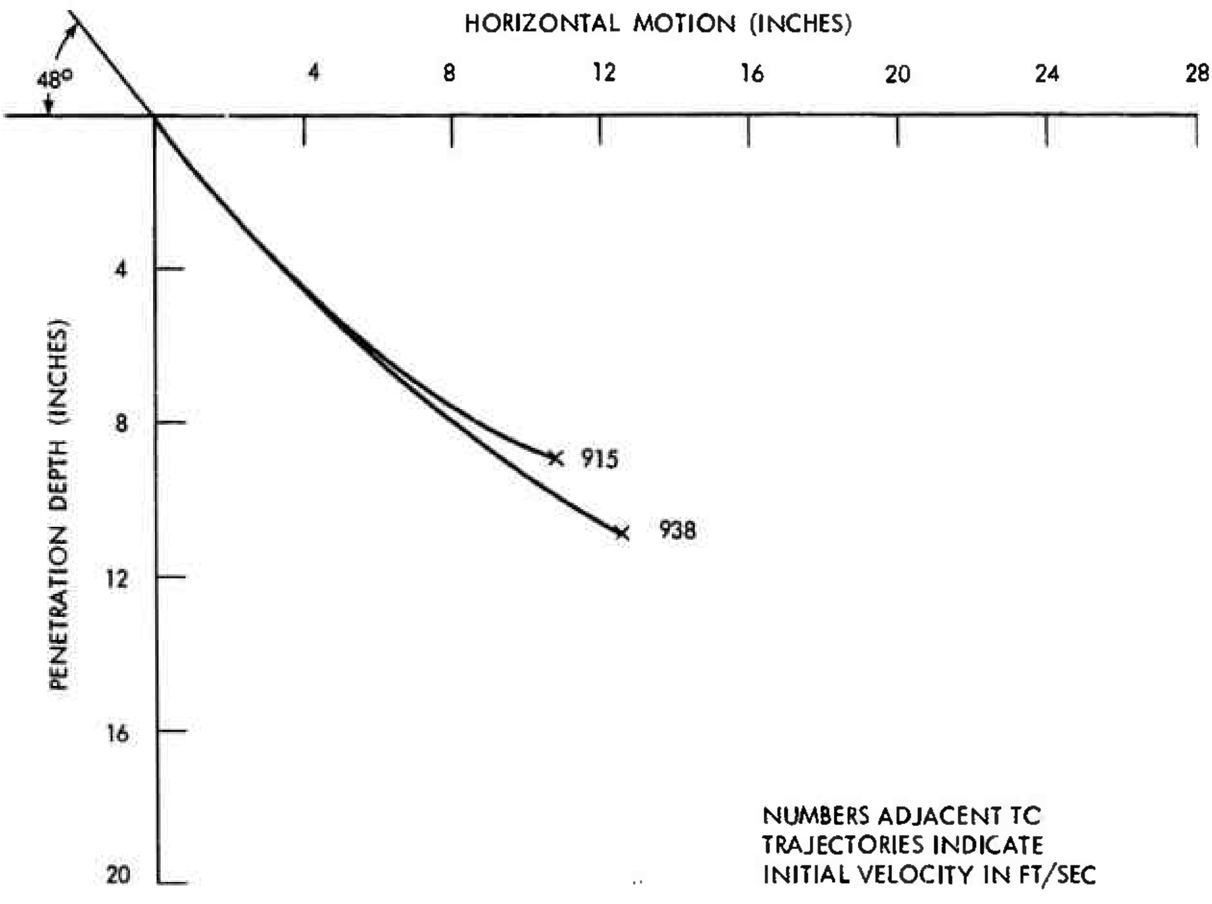

FIG. 8b TRAJECTORY DATA OF FLAT NOSE CONFIGURATION AT 48° IMPACT ANGLE IN HARD CLAY

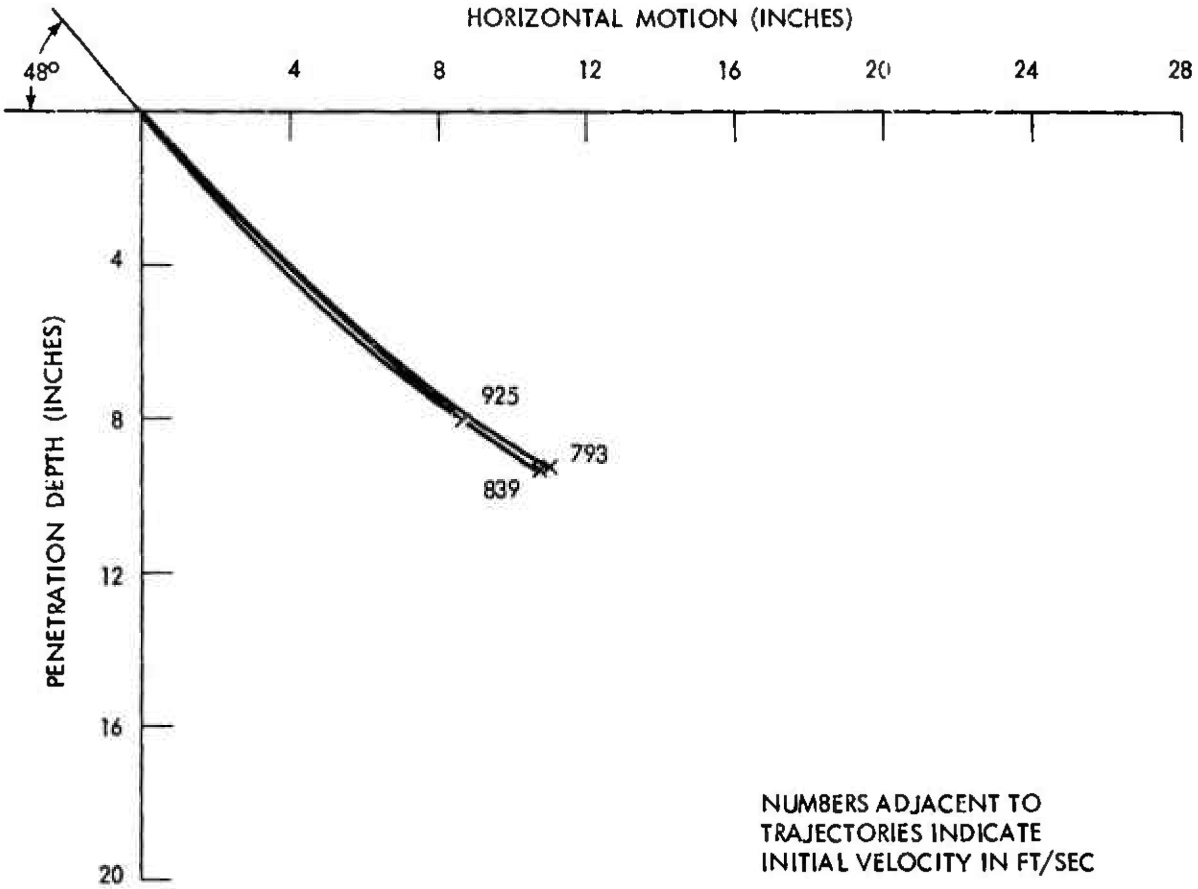

FIG. 8c TRAJECTORY DATA OF FLAT NOSE CONFIGURATION AT 48° IMPACT ANGLE IN STRATIFIED LAYERS OF HARD CLAY AND SAND.

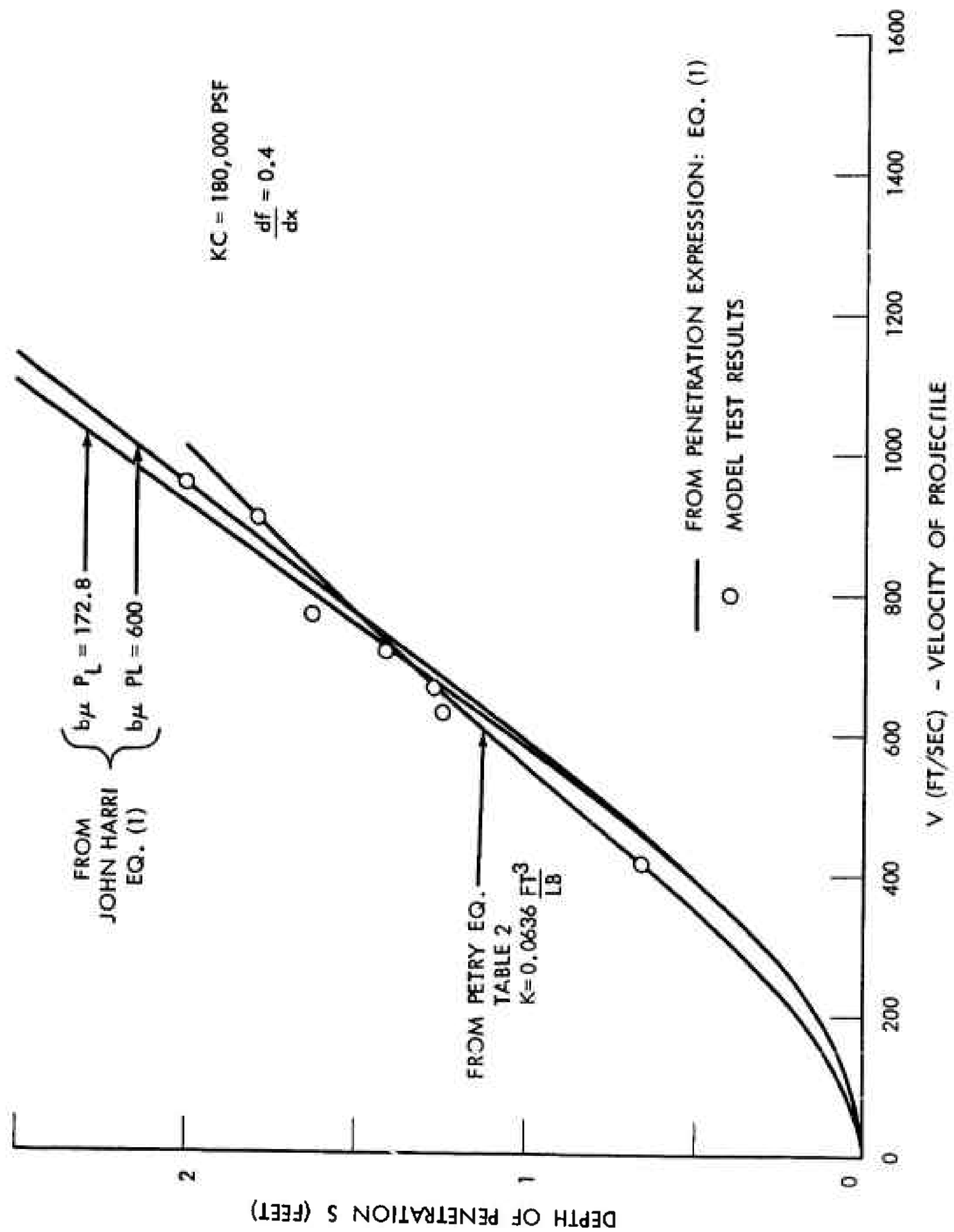

FIG. 9 SOIL CHARACTERISTICS FROM PARAMETRIC STUDY

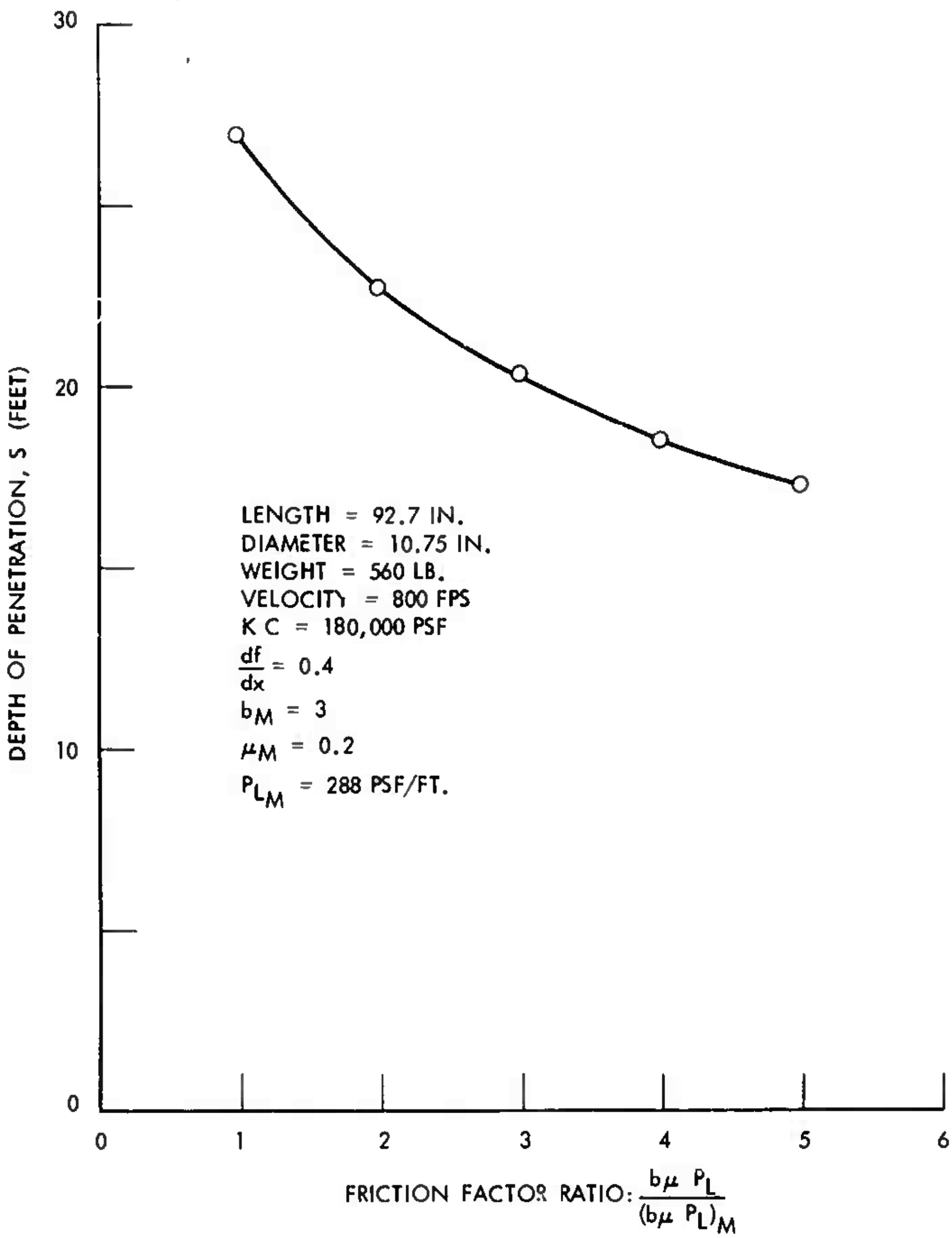

FIG. 10 SIGNIFICANCE OF FRICTION ENERGY TERM IN ACTUAL TESTS.

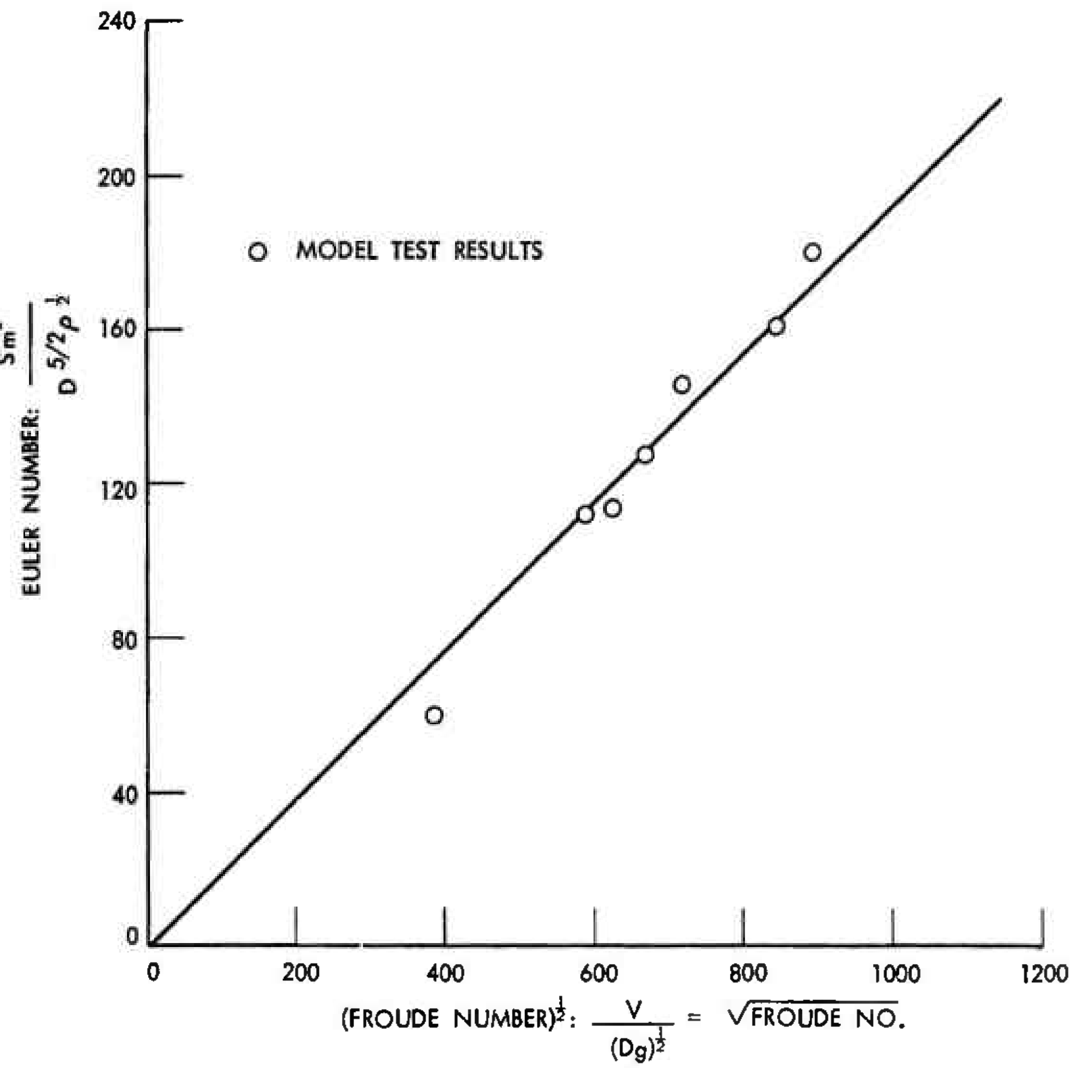

FIG. 11 DIMENSIONLESS PENETRATION RESULTS

APPENDIX A

Dimensional analysis

$$f, S, V, m, \sigma, D, \rho, g, \mu, \alpha = 0$$

	S	V	m	σ	D	ρ	g	μ	α
m	0	0	1	1	0	1	0	0	0
L	1	1	0	-1	1	-3	1	0	0
T	0	-1	0	-2	0	0	-2	0	0

Dimensionless product = number of variables - rank of matrix

Dimensionless Product = 9-3 = 6

Letting $\pi_5 = \mu$, $\pi_6 = \alpha$ and putting the most important parameter first, we have:

$$K_3 + K_4 + K_6 = 0$$

$$K_1 + K_2 - K_4 + K_5 - 3K_6 + K_7 = 0$$

$$-K_2 - 2K_4 - 2K_7 = 0$$

Assign any arbitrary values to K_1, K_2, K_3, K_4 and values for K_5, K_6, K_7 can be obtained. Let

$$K_1 = 1,\ K_2 = K_3 = K_4 = 0,$$

$$K_2 = 1,\ K_1 = K_3 = K_4 = 0,$$

$$K_3 = 1,\ K_1 = K_2 = K_4 = 0,$$

$$K_4 = 1,\ K_1 = K_2 = K_3 = 0,$$

$$K_5 = -1,\ K_6 = K_7 = 0$$

$$K_5 = -\tfrac{1}{2},\ K_6 = 0,\ K_7 = -\tfrac{1}{2}$$

$$K_5 = -3,\ K_6 = -1,\ K_7 = 0$$

$$K_5 = -1,\ K_6 = -1,\ K_7 = -1$$

We obtain the following fundamental system of solution:

	S	V	m	σ	D	ρ	g	μ	α
π_1	1	0	0	0	-1	0	0	0	0
π_2	0	1	0	0	$-\frac{1}{2}$	0	$-\frac{1}{2}$	0	0
π_3	0	0	1	0	-3	-1	0	0	0
π_4	0	0	0	1	-1	-1	-1	0	0
π_5	0	0	0	0	0	0	0	1	0
π_6	0	0	0	0	0	0	0	0	1

$$\pi_1 = \frac{S}{D}$$

$$\pi_2 = \frac{V}{(Dg)^{\frac{1}{2}}}$$

$$\pi_3 = \frac{m}{D^3\rho}$$

$$\pi_4 = \frac{\sigma}{D\rho g}$$

$$\pi_5 = \mu$$

$$\pi_6 = \alpha$$

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13. ABSTRACT

The effectiveness of a weapon system using the Mk 82 bomb requires that the bomb follow a specific trajectory during earth penetration to a terminal location of desired depth. This report presents the results of a preliminary investigation of the effect of nose shape, impact velocity, and impact angle on the trajectory of 1/25-scale models of the Mk 82 low-drag bomb in a silty sand soil. It was found that a spherical nose configuration achieves a relatively consistent and reproducible trajectory of the desired shape, and its response is less sensitive to impact angle and flight attitude than either the ogival or conical nose configurations. Scaling equations, such as those of Poncelet, Petry, Laumbach and Young, were used to predict the response of the prototype from the model tests. A theoretical expression for vertical penetration developed by John Harri, reference (1), was found to be applicable in the prediction of the response of the prototype.

Additional tests were conducted to determine the effect of the medium on the trajectory of the projectile. From tests into clay, sand, and stratified layers of clay and sand, it was found that the effectiveness of modeling depends on the knowledge of the properties of the penetrated medium.

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By direction

This publication is changed as follows:

Page 3, replace equation (1) with the following and put an equal sign in front of the equation above equation (1).

$$S = \frac{-[KC + \frac{1}{4}\frac{\rho}{g}(\frac{df}{dx})^2 V^2 - \frac{W}{A_n}] + \sqrt{[KC + \frac{1}{4}\frac{\rho}{g}(\frac{df}{dx})^2 V^2 - \frac{W}{A_n}]^2 + \frac{MV^2}{A_n} b\mu \frac{A_B}{A_n} P_L}}{b\mu \frac{A_B}{A_n} P_L} \qquad (1)$$

Insert this change sheet between the cover and the title page of your copy. Write on the cover "Change 1 inserted"

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